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Title: Radiation-Generating Device Safety Self-Study

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Intended for: Online Training

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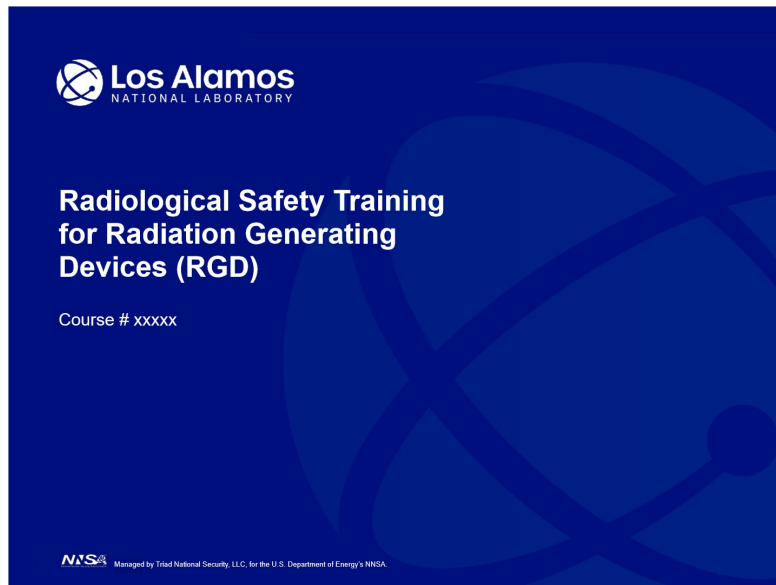


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RGD Safety

1. RGD Safety Course Presentation

1.1 Radiological Safety Training for Radiation-Generating Devices




1.2 Training Overview

Training Overview

This training is targeted for individuals who have, or potentially may be assigned duties as RGD operators, including any operation, maintenance, and radiation safety of RGDs.

The purpose of the course is to illustrate and reinforce the skills and knowledge needed for RGD operators in the basics of safe operation. A primary emphasis of these standards and course is to keep worker exposure to ionizing radiation As Low As Reasonably Achievable (ALARA) and to ensure that no individual receives greater than the maximum permissible equivalent dose.





1.3 Terminal Objectives

Terminal Objectives

TO1: Upon completion of this module, the participants should be able to demonstrate a basic understanding of general radiation protection principles for safe operation of X-ray devices.



1.4 Enabling Objectives

Enabling Objectives

EO1: Describe ionizing radiation.

EO2: Describe what X-rays are, how they are generated, and how they interact with matter.

EO3: Describe the biological effects of X-rays.

EO4: Identify and describe radiation-monitoring instruments and personnel-monitoring devices appropriate for detecting X-rays.

EO5: Demonstrate a familiarity with DOE dose limits, facility-specific administrative controls, ALARA, and the major methods for controlling and minimizing external exposure.



Notes:

1.5 Enabling Objectives

Enabling Objectives

EO6: Identify and describe protective measures that restrict or control access to X-ray areas and devices, and warn of X-ray hazards; and be able to identify and describe work documents that provide specific procedures to ensure safe operation of RGDs.

EO7: Identify and describe the categories of Radiation Generating Devices.

EO8: Explain who is responsible for implementing X-ray safety policies and procedures and describe their specific responsibilities.

EO9: Identify causes of accidental exposures.

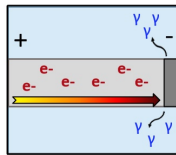


1.6 Lesson Modules

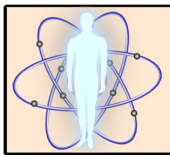
Lesson Modules



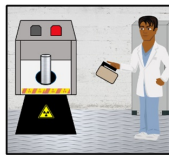
1: RP Principles



2: Production of X-Rays



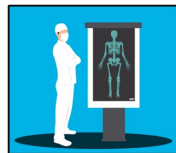
3: Biological Effects



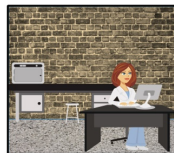
4: Radiation Detection



5: Protective Measures



6: Radiation Generating Devices



7: Responsibilities

Click the next button after completing all lessons



1.7 Conclusion

Conclusion

Congratulations! You have successfully completed the Radiation Generating Device Safety Training. Click the EXIT COURSE button below to close this lesson.



EXIT COURSE

2. Module 4 - Radiation Detection

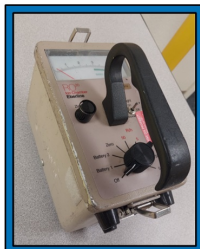
2.1 Module 4 Objectives

Module 4 – Radiation Detection

Upon completion of this module, the participants should understand which radiation-monitoring instruments and which personnel-monitoring devices are appropriate for detecting X-rays.

EO1: Identify the instruments used for X-ray detection.

EO2: Identify the devices used for personnel monitoring.



2.2 Performing Radiation Surveys

Radiation Surveys

Radiation protection surveys should be conducted on all new or newly installed radiation generating devices (RGD) by the RGD Control Office and repeated at a frequency determined by P-121, *Radiation Protection* and RP-PROG-TP-200, *Radiation Protection Manual*.

The RGD Office may place an "Out-of-Service" tag on RGDs if compliance surveys / inspections are not conducted when required.



2.3 Compliance Surveys

Compliance Surveys

Compliance surveys are required:

- Before a new RGD is deemed "operable"
- When an RGD has been moved or reoriented (except portable RGDs)
- When an RGD is modified or refurbished
- Following maintenance that may affect RGD output
- When RGD operations are modified
- Occupancy of adjacent areas change
- If an RGD fails a safety or interlock check
- Before resuming operation of an RGD which had been red tagged (out of service)
- LANL-owned, non-portable RGDs returned from off-site
- Annually, or at least on the frequency designated in P121, table 18-2

Table 18-2. Minimum Requirements by RGD Installation Class

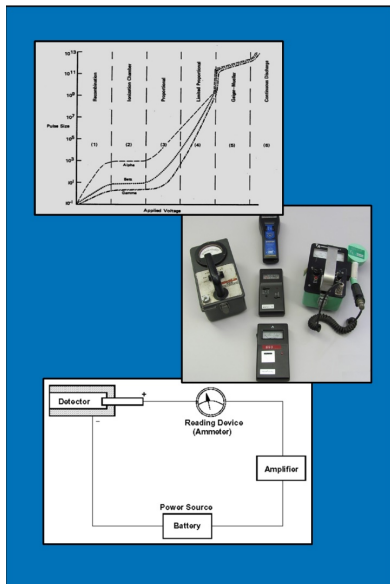
Installation Class	Compliance Survey / Inspection	Approach Survey*	Training†	Safety Feature Inspection‡	Interlock Check‡
Unshielded Certified sealed	Annual	None Required if a whole body dose of 100 mrem in an hour or extremely dose of 1,000 mrem in an hour was possible during operation.	None Custodians, RW and RGD Safety and operating procedures. Operators, GERT and operating procedure.	None Before use each operating day or before a period of uninterrupted use.	None Not to exceed 6 months.
Exempt shielded	Annual	Required if a whole body dose of 100 mrem in an hour or extremely dose of 1,000 mrem in an hour was possible during operation.	Custodians, RW and RGD Safety and operating procedures. Operators, GERT and operating procedure.	Before use each operating day or before a period of uninterrupted use.	Not to exceed 6 months.
Shielded	Annual	Required if a whole body dose of 100 mrem in an hour or extremely dose of 1,000 mrem in an hour was possible during operation.	RW and RGD Safety and operating procedure.	Before use each operating day or before a period of uninterrupted use.	Not to exceed 6 months.
Open	Annual	Required if a whole body dose of 100 mrem in an hour or extremely dose of 1,000 mrem in an hour was possible during operation.	RW and RGD Safety and operating procedure.	Before use each operating day or before a period of uninterrupted use.	Not to exceed 6 months.

* See requirements for an approach survey in Article 121.5.

† These training requirements are specifically for RGD operations; other radiological conditions may dictate additional training (see Chapter 5 for the list of radiological training).

‡ Safety feature inspection / interlock checks must be conducted on this frequency unless an alternative is approved by the RGD Office that will not harm the RGD or safety features and will not obstruct or jeopardize the work associated with the RGD.

2.4 X-Ray Detection Instruments



X-Ray Detection Instruments

External exposure controls used to minimize the dose to workers are based on the data taken with portable radiation-monitoring instruments during a radiation survey.

An understanding of these instruments is important to ensure that the data obtained is accurate and appropriate for the source of radiation.

NOTE : Completion of this training will NOT qualify individuals to use radiation detection instrumentation. Specific instrument training is required.

2.5 Instrument Considerations

Instrument Considerations

Many factors can affect how well the survey measurement reflects the actual conditions, including:

- Selection of the appropriate instrument based on the type and energy of the radiation and the intensity
- Correct operation of the instrument based on its operating characteristics and limitations
- Calibration of the instrument to a known radiation field similar in type, energy, and intensity to the radiation field being measured



2.6 Performing the Survey

Performing the Survey

RGD operators, working under a Radiological Surveillance Authorization Agreement (RSAA) often use a radiation monitoring instrument for the **detection** of x-rays.

During an approach survey, an RGD operator may use an ion chamber to verify that the device is off before entry into the area.

The **measurement** of x-rays is normally the job of a qualified radiological control technician (RCT) from the RGD Control Office.

RP-PROG-FORM-103, Radiation Generating Device (RGD) Compliance Survey Report



2.7 Instrument Classifications

Instrument Classifications

Instruments such as Geiger-Mueller (GM) counters, which count individual photons in counts per minute (cpm), are sensitive to X-rays. However, because a low-energy and a high-energy photon are each assigned one count, the GM counters tend to over respond to the low-energy photons.

Measurement of radiation dose rates and surveys of record require an instrument that reads in roentgen or rem per hour (R/hour, mR/hour, rem/hour, mrem/hour). Ion chambers, which detect current instead of counting pulses, have the flattest energy response.

Other specialized monitoring instruments are often used by the RGD Control Office RCTs.



RO-20 (Ion Chamber)




Teletector (GM Detector)



2.8 Personnel Monitoring Devices


Personnel Monitoring Devices

Whole-Body Dosimeters




- Whole-body dosimeters must be worn when operating intentional RGDs
- Thermoluminescent dosimeters (TLDs) accurately measure radiation and are used to assess the legal dose of record
- Records are available to the workers from RP-SVS at any time
- Must be worn between neck and waist with two round Mylar windows facing outward

Alarming Dosimeters



- Required for entry into High or Very High Radiation Areas
- Must be worn when required by RWP
- Worn with primary TLD located on the chest area between waist and neck
- Work should be stopped when alarming dosimeter readings indicate total exposure or rate of exposure substantially greater than planned



2.9 Knowledge Check

(Drag and Drop, 10 points, 2 attempts permitted)

Drag-and-Drop Knowledge Check

TLD
EPD

Required when operating intentional RGDs

Used to assess the legal dose of record

Must be worn when required by RWP

Worn with TLD between waist and neck

Required for entry into HRA and VHRA

Records to workers available anytime

Must be worn with Mylar outward

Contains an alarming feature

Drag Item	Drop Target
Used to assess the legal dose of record	Rectangle 2

Records to workers available anytime	Rectangle 2
Must be worn with Mylar outward	Rectangle 2
Required when operating intentional RGDs	Rectangle 2
Must be worn when required by RWP	Rectangle 3
Required for entry into HRA and VHRA	Rectangle 3
Contains an alarming feature	Rectangle 3
Worn with TLD between waist and neck	Rectangle 3

Drag and drop properties
Snap dropped items to drop target (Free)
Delay item drop states until interaction is submitted

Feedback when correct:

That's right! You selected the correct response.

Feedback when incorrect:

You did not select the correct response.

Correct (Slide Layer)

Drag-and-Drop Knowledge Check

The slide shows a central grey box with the word 'Correct' in bold. Below it, the text reads 'That's right! You selected the correct response.' At the bottom of this box is a 'Continue' button. In the background, there are two large blue rectangular areas. Below these, there is a grey-bordered container with two columns of text boxes. The left column contains: 'Required when operating intentional RGDs', 'Used to assess the legal dose of record', 'Must be worn when required by RWP', and 'Worn with TLD between waist and neck'. The right column contains: 'Required for entry into HRA and VHRA', 'Records to workers available anytime', 'Must be worn with Mylar outward', and 'Contains an alarming feature'.

Correct

That's right! You selected the correct response.

Continue

Required when operating intentional RGDs	Required for entry into HRA and VHRA
Used to assess the legal dose of record	Records to workers available anytime
Must be worn when required by RWP	Must be worn with Mylar outward
Worn with TLD between waist and neck	Contains an alarming feature

Incorrect (Slide Layer)

Drag-and-Drop Knowledge Check

The slide shows a central grey box with the word 'Incorrect' in bold. Below it, the text reads 'You did not select the correct response.' At the bottom of this box is a 'Continue' button. In the background, there are two large blue rectangular areas. Below these, there is a grey-bordered container with two columns of text boxes, identical to the ones in the 'Correct' slide. The left column contains: 'Required when operating intentional RGDs', 'Used to assess the legal dose of record', 'Must be worn when required by RWP', and 'Worn with TLD between waist and neck'. The right column contains: 'Required for entry into HRA and VHRA', 'Records to workers available anytime', 'Must be worn with Mylar outward', and 'Contains an alarming feature'.

Incorrect

You did not select the correct response.

Continue

Required when operating intentional RGDs	Required for entry into HRA and VHRA
Used to assess the legal dose of record	Records to workers available anytime
Must be worn when required by RWP	Must be worn with Mylar outward
Worn with TLD between waist and neck	Contains an alarming feature

Try Again (Slide Layer)

Drag-and-Drop Knowledge Check

Incorrect

That is incorrect. Please try again.

Try Again

Required when operating intentional RGDs	Required for entry into HRA and VHRA
Used to assess the legal dose of record	Records to workers available anytime
Must be worn when required by RWP	Must be worn with Mylar outward
Worn with TLD between waist and neck	Contains an alarming feature

3. Module 3 - Biological Effects

3.1 Module 3 Objectives

Module 3 – Biological Effects

Upon completion of this module, the participants should understand biological effects of X-rays and the importance of protective measures for working with or around X-rays.

EO1: Outline the early history of X-rays and the consequences of working with or around X-rays without protective measures.

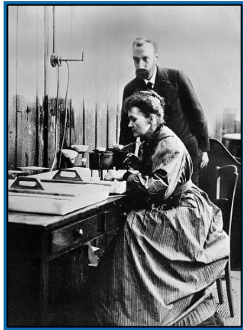
EO2: Identify factors that determine the biological effects of X-ray exposure.

EO3: State the differences between thermal and X-ray burns.


EO4: Identify the signs and symptoms of an acute dose from X-rays.

EO5: Explain the effects of chronic exposure to X-rays.

EO6: Identify the difference between somatic and heritable effects.

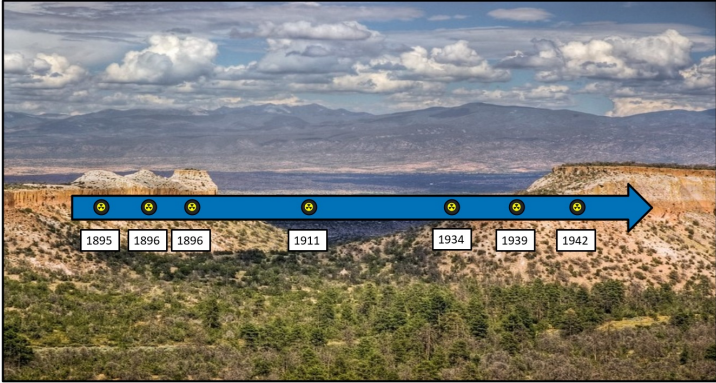


Pierre and Marie Curie

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3.2 Discovery of X-rays

Early History of X-Rays – Discovery of X-Rays



Select the next button after viewing all events


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3.3 Discovery of Harmful Effects

Discovery of Harmful Effects

In the early days, virtually no protective measures were used when performing tests involving X-rays. Not long after the discovery people began to learn of the harmful effects. Individuals that were exposed to very large doses of radiation were reported to experience effects such as:

- Skin damage
- Hair loss
- Eye injuries
- Lesions
- Skin sloughing off
- Cancer



Thomas Edison's assistant, Clarence Dally's hand after extreme exposure. Dally died from metastatic carcinoma eight years after his first x-ray.

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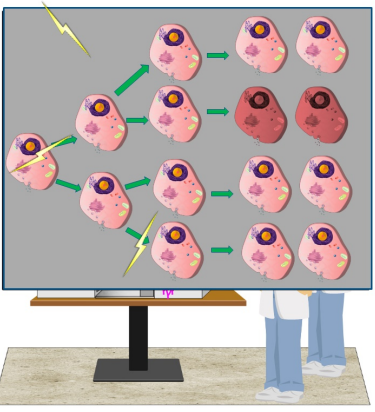
3.4 Biological Effects

Biological Effects of Ionization


X-rays can penetrate the human body and ionize atoms. This process creates radicals that can break or modify chemical bonds within critical biological molecules.

Cell injury or death can occur from this, and may be the cause of radiation induced cancer. In some cases, altered cells are able to repair the damage.

The daughter cells may inherit the effects through cell division and after several divisions can result with altered characteristics. If enough cells in a body organ are injured or altered, the functioning of the organ can be impaired.

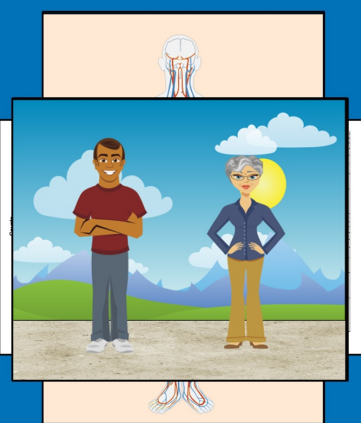


The diagram illustrates the biological effects of ionization. It shows a grid of cells. Some cells are being hit by lightning bolts, representing ionization. Other cells are shown dividing into two daughter cells, indicated by green arrows. The cells are depicted as pink, irregular shapes with a nucleus. The background is a light blue grid.



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3.5 Biological Effect Factors



The illustration shows a person standing in a landscape with mountains and a sun. Above the person is a diagram of the human body showing internal organs. The person is wearing a red shirt and blue pants. The landscape has green hills and a blue sky with clouds. The sun is a yellow circle. The diagram of the human body shows internal organs in red and blue.

Biological Effect Factors

Several factors contribute to the biological effects of X-ray exposure, including:

- Dose rate
- Total dose received
- Energy of the radiation
- Location of the body exposed
- Individual sensitivity
- Cell sensitivity

3.6 Dose Rate

Dose Rate

Acute dose: A large amount of radiation received in a short period (seconds to days).

Chronic dose: Smaller amounts of radiation taken in over a longer period of time (months to years).

For the same total amount of dose, an acute dose is more damaging than a chronic dose. It is believed that this effect is due to the ability of cells to repair damage over time. With an acute dose, a cell may receive many "hits" without sufficient time to repair the damage.



3.7 Total Dose

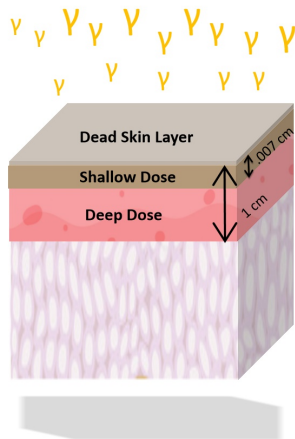
Total Dose Received

Dose Received	Symptoms
< 25 Rem	<ul style="list-style-type: none">• Generally not clinically observable
25 – < 100 Rem	<ul style="list-style-type: none">• Generally no symptoms• May show mild prodromal effects (nausea and anorexia)• Possible bone marrow damage (decrease in red-white blood and platelet counts)
100 – 300 Rem	<ul style="list-style-type: none">• May result in mild to severe nausea, malaise, anorexia, and infection• Hematologic damage is more severe

3.8 Energy of the Radiation

Energy of the Radiation

The energy of X-rays can vary from less than 1 keV up to more than 10 MeV. The higher the energy of the X-ray, the more penetrating it will be into body tissue. Lower energy X-rays are largely absorbed in the skin. They can cause a significant skin dose but may contribute little dose to the whole body (depending on energy).

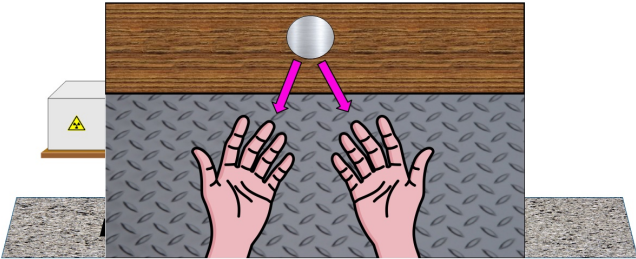


The diagram illustrates the penetration of radiation into the skin. It shows a cross-section of the skin with three distinct layers: the 'Dead Skin Layer' at the top, followed by the 'Shallow Dose' region, and the 'Deep Dose' region. The 'Dead Skin Layer' is labeled with a thickness of 0.007 cm. The 'Shallow Dose' region is indicated by a double-headed arrow, and the 'Deep Dose' region is indicated by a double-headed arrow with a thickness of 1 cm. Yellow 'Y' symbols representing radiation are shown entering from the top and penetrating into the skin layers. The Los Alamos National Laboratory logo is in the bottom left corner.

3.9 Area of the Body Exposed

Area of the Body Exposed

Just as a burn to a large portion of the body is more damaging than a burn confined to a smaller area, so is a radiation dose to the whole body more damaging than a dose to only a small area. In addition, the larger the area, the more difficult it is for the body to repair the damage.




The diagram shows a pair of hands positioned in front of a grey, textured surface. Above the hands, a silver sphere is shown with two pink arrows pointing down towards the hands, indicating the direction of radiation exposure. To the left of the hands, there is a small white box with a yellow radiation warning symbol. The Los Alamos National Laboratory logo is in the bottom left corner.

3.10 Individual Sensitivity

Individual Sensitivity

Some individuals are more sensitive to radiation than others. Age, gender, and overall health can have an effect on how the body responds to radiation exposure.



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3.11 Cell Sensitivity

Cell Sensitivity

Law of Bergonié and Tribondeau: The radiosensitivity of a tissue is directly proportional to its reproductive capacity and inversely proportional to its degree of differentiation.

- Cells that are more sensitive to radiation are **radiosensitive**. Characteristics of a radiosensitive cell include: having a high division rate, high metabolic rate, non-specialized, and are well nourished
- Cells that are less sensitive to radiation are **radioresistant**

Radiosensitive	Radioresistant
1. Germinal	1. Bone
2. Hematopoietic	2. Liver
3. Epithelium of the skin	3. Kidney
4. Epithelium of the gastrointestinal tract	4. Cartilage
	5. Muscle
	6. Nervous system tissue

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3.12 X-Ray Damage and Thermal Burns


X-Ray Damage and Thermal Burns

Radiation Burn

- No sensation or feeling with exposure to x-rays
- Damage is done to immature basal skin cells
- Older skin cells cannot be replaced after they slough off
- Slow to heal or never heal
- Can lead to gangrene and amputation
- Severity depends on energy of x-rays and time of exposure

Thermal Burn


- Immediate warning of burn from high temperature object
- Burns from the outside in
- As long as basal cells are not damaged, skin can be replaced as new skin grows
- Severity depends on time of exposure and proximity of heat source



3.13 Symptoms of Accidental Exposure

Symptoms of Accidental Exposure to X-Rays

~ 600 rad	~ 1,000 rad	~ 2,000 rad	~ 3,000 rad
<ul style="list-style-type: none">• No immediate pain• Sensation of warmth• Initial reddening after several hours• Scaling or peeling will follow after reddening fades away over a few weeks• Cataracts form if acute dose delivered to the eyes• Further medical treatment typically not needed	<ul style="list-style-type: none">• Serious tissue damage similar to second-degree burn• Reddening and inflammation occurs• Swelling and tenderness• Blisters within 1-3 weeks, which will begin to break open and lead to possible infection• Immediate medical attention is required	<ul style="list-style-type: none">• Severe tissue damage equivalent to scalding or chemical burn• Intense pain and swelling in hours• Damage to blood vessels• Immediate medical attention is required• Surgical removal of tissue and skin grafting may be necessary	<ul style="list-style-type: none">• Complete tissue destruction• Exposure of this degree requires surgical removal of affected tissue



3.14 Somatic Effects

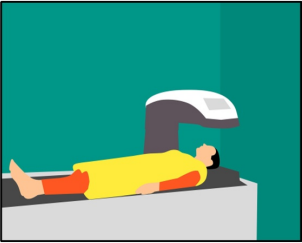
Somatic Effects

Early Acute Somatic Effects

- Most common injury from x-ray generating equipment occurs when a body part is exposed to the beam resulting in a radiation burn
- Severity of the burn depends on beam energy and length of exposure

Latent Effects from Radiation Exposure

- The probability of a latent effect appearing several years after radiation exposure depends on the amount of the dose
- The higher the dose, the greater the risk of developing a health effect
- Possibility of developing fatal cancer



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Notes:

3.15 Somatic Effects

Somatic Effects

- Risk of Developing Cancer from Low Doses

- It is not possible to absolutely quantify the risk of cancer from low doses of radiation
- Risk of health effects from low doses is inferred from effects observed from high acute doses
- Health effects from doses below 10 rem are too small to measure

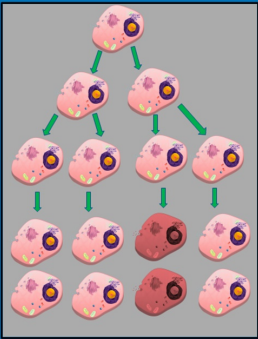
- Effects of Prenatal Exposure

- Embryo/fetus is highly sensitive to radiation
 - High cellular division
 - High number of non-specialized cells
- Pregnant workers are encouraged to declare their pregnancy in writing
- Dose limit is 500 mrem during the term of the pregnancy per 10 CFR 835.20

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Notes:

3.16 Heritable Effects



The diagram illustrates a cell lineage tree. It starts with a single cell at the top, which divides into two cells. These two cells divide into four cells, which then divide into eight cells. The cells are represented as pink ovals with a nucleus and some have small blue dots. Green arrows indicate the flow of genetic information from parent cells to daughter cells. The tree shows how a single cell can give rise to a population of cells, and how any changes in the parent cell can be passed on to all its descendants.

Heritable Effects

Heritable effects are biological effects inherited by children from their parents at conception.


Irradiation of the reproductive organs can damage cells that contain heritable information passed on to offspring.

Radiation-induced heritable effects do not result in genetic diseases that are uniquely different from those that occur naturally. Extensive observations of the children of Japanese atomic bomb survivors have not revealed any statistically significant hereditary health effects.

3.17 Knowledge Check

(True/False, 10 points, unlimited attempts permitted)

Generally, no clinical observable symptoms are detected until receiving and acute dose of 25 rem.



The illustration shows a male doctor in a white lab coat standing with his hands raised in a questioning gesture. Next to him is a patient wearing an orange protective suit and a mask, sitting on the floor and holding a clipboard and a pen. The scene is set on a grey mat.

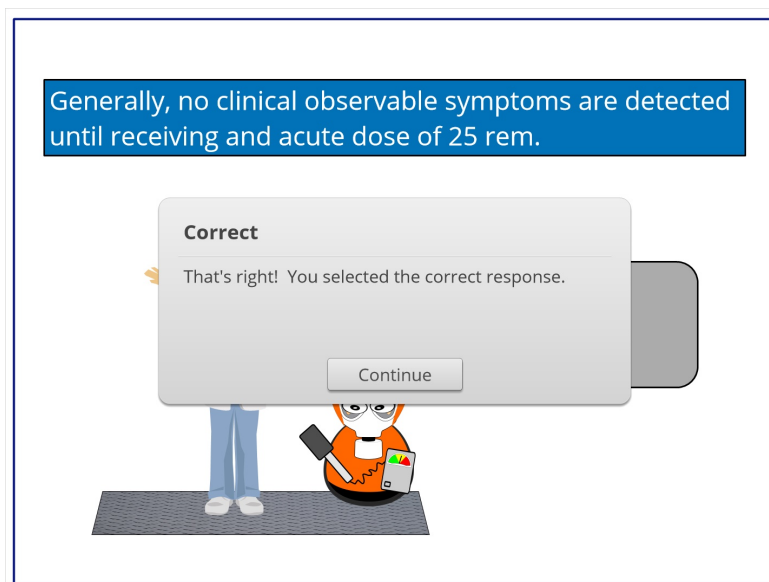
☒ True
☐ False

Correct	Choice
X	True
	False

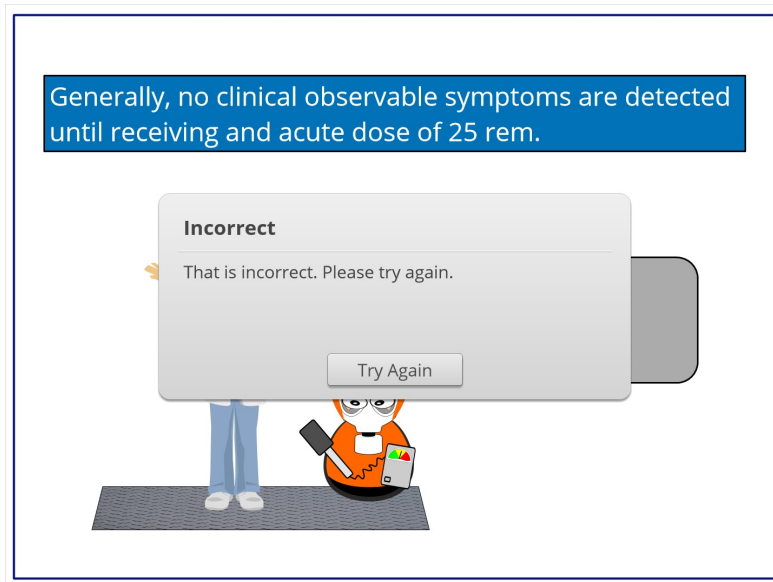
Feedback when correct:

That's right! You selected the correct response.

Correct (Slide Layer)

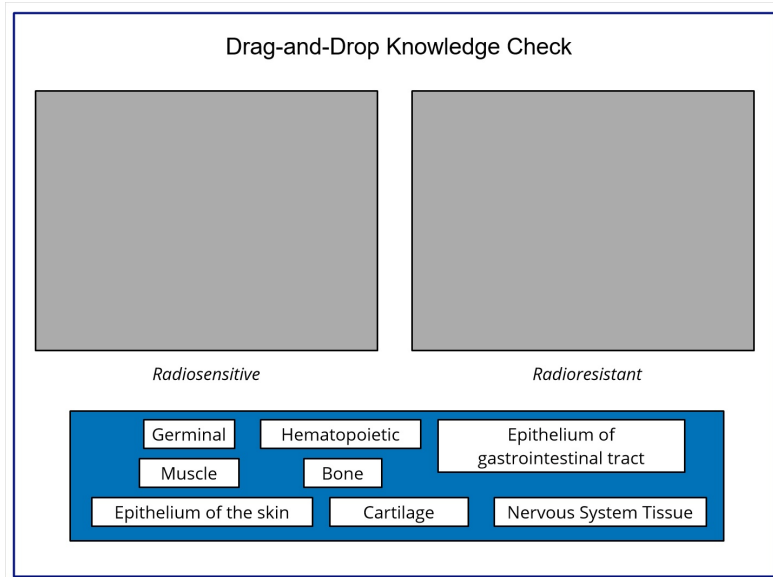


Try Again (Slide Layer)



3.18 Knowledge Check

(Drag and Drop, 10 points, 2 attempts permitted)



Drag Item	Drop Target
Germinal	Rectangle 2

Epithelium of the skin	Rectangle 2
Epithelium of gastrointestinal tract	Rectangle 2
Hematopoietic	Rectangle 2
Nervous System Tissue	Rectangle 3
Cartilage	Rectangle 3
Bone	Rectangle 3
Muscle	Rectangle 3

Drag and drop properties
Snap dropped items to drop target (Free)
Delay item drop states until interaction is submitted

Feedback when correct:

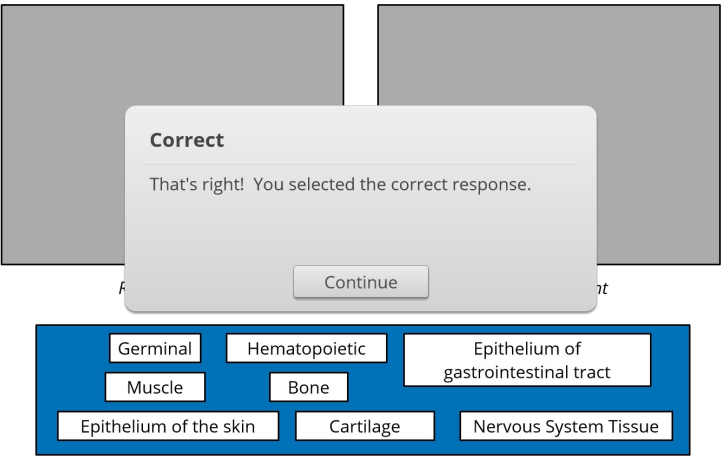
That's right! You selected the correct response.

Feedback when incorrect:

You did not select the correct response.

Correct (Slide Layer)

Drag-and-Drop Knowledge Check



Correct

That's right! You selected the correct response.

Continue

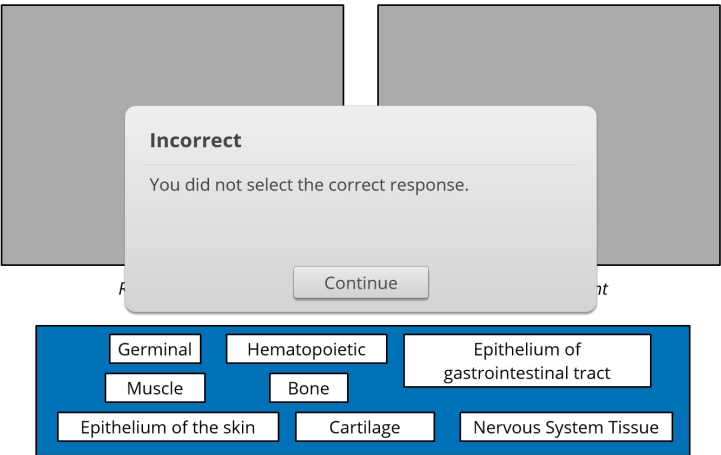
Germinal Hematopoietic Epithelium of gastrointestinal tract

Muscle Bone

Epithelium of the skin Cartilage Nervous System Tissue

Incorrect (Slide Layer)

Drag-and-Drop Knowledge Check



Incorrect

You did not select the correct response.

Continue

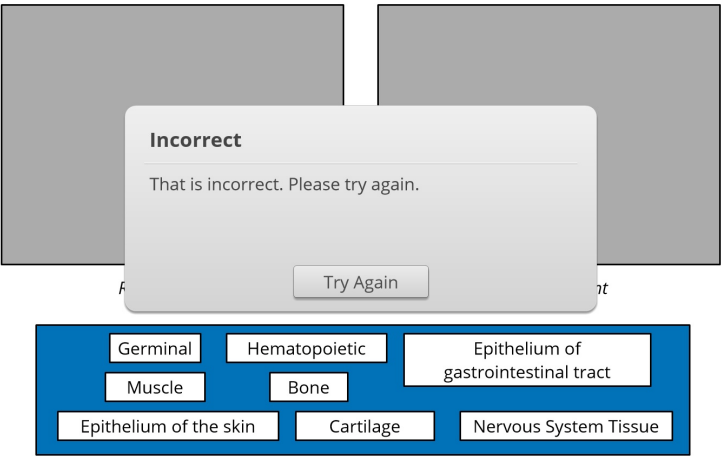
Germinal Hematopoietic Epithelium of gastrointestinal tract

Muscle Bone

Epithelium of the skin Cartilage Nervous System Tissue

Try Again (Slide Layer)

Drag-and-Drop Knowledge Check



Incorrect

That is incorrect. Please try again.

Try Again

Germinal Hematopoietic Epithelium of gastrointestinal tract

Muscle Bone


Epithelium of the skin Cartilage Nervous System Tissue

4. Module 6 - RGDs

4.1 Module 6 Objectives

Module 6 – Radiation Generating Devices

Upon completion of this module, the participants should understand the categories of radiation generating devices and the hazards associated with each.




EO1: Contrast incidental and intentional RGDs.

EO2: Contrast analytical and industrial RGDs.

EO3: Identify open and enclosed beam installations.

EO4: Describe the safety features essential for operation of industrial and analytical systems.

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4.2 RGD Overview

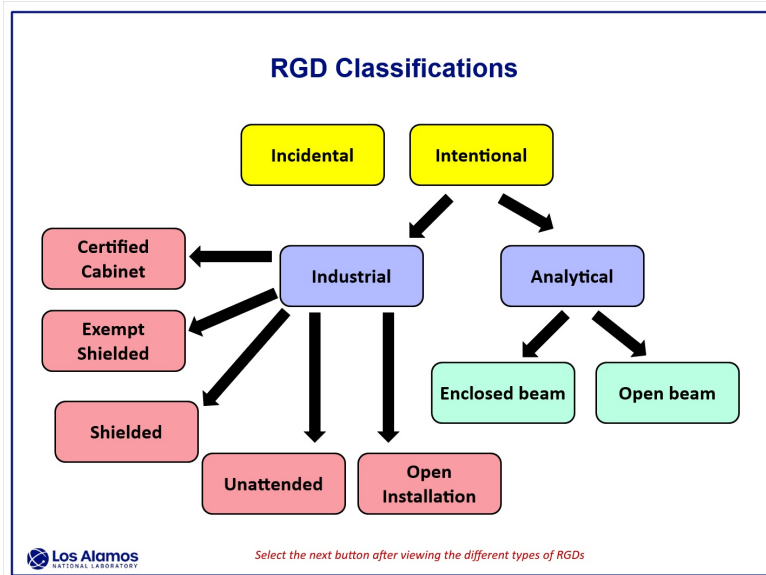
Radiation Generating Devices

A radiation generating device (RGD) is a device with a reasonable potential to expose an individual to significant hazardous levels of ionizing radiation. Examples include:

- Neutron generators
- Research and analytical x-ray machines
- Electron microscopes
- Radioactive sealed sources (RSS) used as irradiators
- Particle accelerators (< 10 MeV and single purpose)
- X-ray producing radiography equipment
- Electromagnetic pulse generators
- Cabinet X-ray machines used for security applications



4.3 RGD Classifications



4.4 Incidental RGDs

Incidental

Incidental RGD – Produces X-rays that are not wanted or used as a part of the designed purpose of the machine. Shielding of an incidental X-ray device should preclude significant exposure.

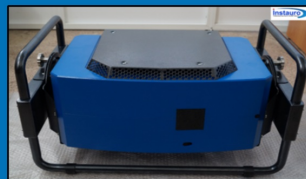
- Computer monitors
- Televisions
- Electron microscopes
- High-voltage electron guns
- Electron beam welders
- Electrostatic separators



Any device that combines high voltage (> 40 kV), a vacuum, and a source of electrons could, in principle, produce X-rays.



4.5 Intentional RGDs



Intentional

Intentional RGDs generate an X-ray beam for a particular use.

This type of RGD is divided into two different classifications, analytical and industrial. Intentional RGDs are typically housed within a fixed, interlocked, and/or shielded enclosure or room. Devices include:

- X-ray diffraction and fluorescence analysis systems
- Flash X-ray systems
- Medical X-ray machines
- Industrial cabinet and non-cabinet X-ray equipment
- Neutron generators

4.6 Analytical RGDs

Analytical

Analytical radiation generating devices use X-rays for diffraction or fluorescence experiments. Analytical X-ray systems are classified into two types: enclosed beam and open beam systems. These research tools are normally used in materials science.

Safety requirements for analytical RGDs include:

- Control panel labels with the words "CAUTION – THIS EQUIPMENT PRODUCES X-RAYS WHEN ENERGIZED" or equivalent
- Fail-safe lights stating "X-RAYS ON"
- Fail-safe indicators stating "SHUTTER OPEN"
- Fail-safe interlock on access doors and panels
- Beam stops or other barriers
- Appropriate shielding



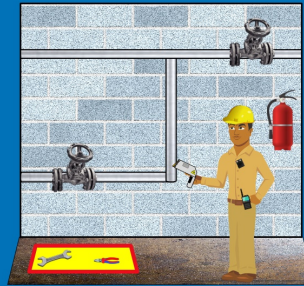
4.7 Industrial RGDs

Industrial

Industrial RGDs are used for radiography, which is the process of using radiation to capture images of the inside of objects or thickness of a material, such as the human body or piping systems.

Classifications of Industrial RGDs:

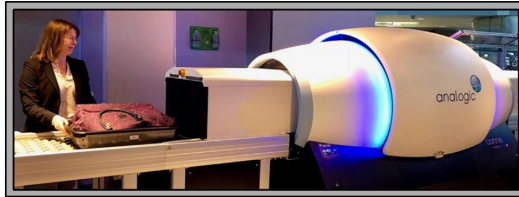
- Certified cabinet
- Exempt shielded
- Shielded
- Unattended
- Open



4.8 Enclosed Beam RGDs

Enclosed-Beam System

- All possible x-ray paths (primary and diffracted) are completely enclosed
- Enclosed-beam systems should be selected over the open-beam system whenever possible
- All RGD components must be in enclosed chamber and inaccessible during use
- Must have shutter with fail-safe interlock to prevent access
- Dose rate measured at 2 inches (5 cm) from the outer surface must not exceed 0.25 mrem per hour during normal operation



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4.9 Open-beam System

Open-Beam System

Required open-beam safety features:

- Each port of the X-ray tube housing must have a beam shutter
- All shutters must have a conspicuous SHUTTER OPEN indicator or fail-safe design
- Shutters at unused ports should be mechanically or electrically secured to prevent casual opening
- Exposure rates adjacent to the system must not exceed 2.5 mrem/hr at 5 cm from the surface of the housing
- A guard or interlock must prevent entry of any part of the body into the primary beam
- Fail-safe interlock that prevents entry

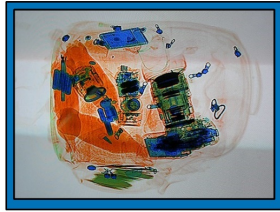
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4.10 Certified Cabinet

Certified Cabinet

A cabinet x-ray installation is similar in principle to the analytical enclosed beam system. The X-ray tube is installed in an enclosure (cabinet) that contains the object being irradiated, provides shielding, and excludes individuals from its interior during X-ray generation. A common example is the X-ray device used to inspect carry-on baggage at airline terminals.

RGDs are classified as certified cabinet x-ray installations only if verified by the manufacturer under 21 CFR 1020.40, are properly labeled by the manufacturer, and the contact dose rate does not exceed 0.5 mrem/hr.



4.11 Exempt Shielded

Exempt Shielded

An RGD is considered as an exempt shielded installation when they:

- Depend on shielding for safe operation
- Do not qualify as cabinet X-ray installations
- Do not require occupancy controls outside the installation
- The contact dose rates are < 0.5 mrem/hr



Exempt shielded installations are inherently safe, and therefore require limited controls to be operated.



4.12 Shielded RGDs



Shielded

RGDs are deemed as shielded installations if they depend on shielding for safe operation, such that dose rates do not exceed 5 mrem/hr at 30 cm from the outside surface of the installation. Anything greater is deemed as open installation.

Shielded installations that are not exempt have associated limitations and controls to commensurate with potential hazards; operators must ensure access control and work control requirements are implemented.

4.13 Open Installation

Open Installation

An open installation RGD has X-ray paths that are not enclosed. An example would be a portable X-ray machine outdoors in an emergency response situation, with the X-ray tube not enclosed in a shielded room. This class is acceptable for use only if the operational requirements prevent the use of one of the other classes.



- Limited mainly to mobile and portable equipment where fixed shielding cannot be used
- High Radiation Areas must either be locked or be under constant surveillance of the operator
- The perimeter of a Radiation Area created by the system must be defined and posted

The operator shall use a suitable calibrated and operable survey instrument to verify that the source is in its fully shielded condition or the X-ray tube has been turned off.

4.14 Open-beam System

Open-Beam System

An open-beam system is a device that does not meet the enclosed-beam standards, in which one or more X-ray beams are not enclosed, making exposure of human body parts possible during normal operation.

The open-beam system is acceptable for use only if an enclosed beam is impractical due to any of the following reasons:

- A need for frequent changes of attachments and configurations
- Adjustments will be needed while the X-ray beam is energized
- Motion of specimen and detector over wide angular limits
- The examination of large or bulky samples will be performed



4.15 Unattended RGDs

Unattended

- An unattended installation consists of equipment designed and manufactured for a specific purpose and does not require personnel in attendance for its operation
- Steps must be taken to ensure that the dose to personnel is less than 100 mrem/year
- A short term limit of 2 mrem/hr may be used provided the expected dose to personnel is less than 100 mrem/year



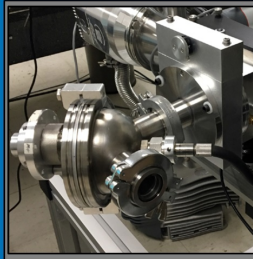
4.16 Exempt RGD Units

Exempt RGD Units

An RGD is considered exempt when it meets all of the following criteria:

- Produces radiation incidentally
- Has a potential across the terminals <15 kV
- Produces radiation fields that are no more than twice the background levels when measured at 5 cm from the device when operated at the prescribed operating parameters
- Used in accordance with the manufacturer's instructions

For more guidance on exempt RGDs, refer to RP-PROG-TP-200, 1825.3 *Exempt RGDs*.



4.17 Summary of Radiation Generating Devices

Summary of Radiation Generating Devices

Category of Installation	Type of RGD	Maximum External Dose Rate	Access	Approach Survey
Analytical	Enclosed Beam	0.25 mrem/hr @ 5 cm	Fully enclosed chamber	Not required
	Open Beam	2.5 mrem/hr @ 5 cm	Beam Guard	Not required
Industrial	Cabinet	0.5 mrem/hr on-contact	Fully enclosed in a cabinet	Required if whole body dose rate of 100 mrem/hr or extremity dose 1,000 mrem/hr possible during operation
	Exempt Shielded	0.5 mrem/hr on-contact	Enclosed	Required if whole body dose rate of 100 mrem/hr or extremity dose 1,000 mrem/hr possible during operation
	Shielded	5 mrem/hr @ 30cm	Locked doors	Required if whole body dose rate of 100 mrem/hr or extremity dose 1,000 mrem/hr possible during operation
	Unattended	2 mrem/hr @ 30cm Not to exceed 100mrem/yr	Secured access panel	Not required
	Open	As Posted	Constant surveillance	Required if whole body dose rate of 100 mrem/hr or extremity dose 1,000 mrem/hr possible during operation

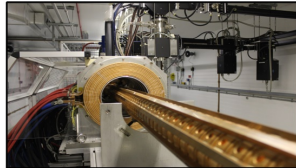


4.18 Knowledge Check

(Matching Drag-and-Drop, 10 points, unlimited attempts permitted)

Drag-and-Drop Knowledge Check

Intentional X-Ray	Designed to generate an X-ray beam for a particular use
Incidental X-Ray	Produces X-rays that are not wanted or used as part of the machine
Analytical X-Ray	Use X-rays for diffraction or fluorescence experiments
Industrial X-Ray	X-ray devices are used for radiography
Enclosed-Beam System	All possible X-Ray paths are completely enclosed



Correct	Choice
Intentional X-Ray	Designed to generate an X-ray beam for a particular use
Incidental X-Ray	Produces X-rays that are not wanted or used as part of the machine
Analytical X-Ray	Use X-rays for diffraction or fluorescence experiments
Industrial X-Ray	X-ray devices are used for radiography
Enclosed-Beam System	All possible X-Ray paths are completely enclosed

Feedback when correct:

That's right! You selected the correct response.

Correct (Slide Layer)

Drag-and-Drop Knowledge Check

Intentional X-Ray ☒ Designed to generate an X-ray beam for a particular use

Incidental X-Ray ☐ Part of the machine

Analytical X-Ray ☐ For experiments

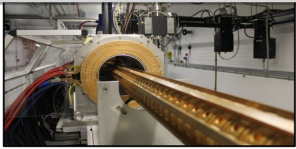
Industrial X-Ray ☐ Radiography

Enclosed-Beam ☐ Fully enclosed

Correct

That's right! You selected the correct response.

Continue



Try Again (Slide Layer)

Drag-and-Drop Knowledge Check

Intentional X-Ray ☒ Designed to generate an X-ray beam for a particular use

Incidental X-Ray ☐ Part of the machine

Analytical X-Ray ☐ For experiments

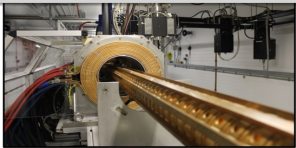
Industrial X-Ray ☐ Radiography

Enclosed-Beam ☐ Fully enclosed

Incorrect

That is incorrect. Please try again.

Try Again

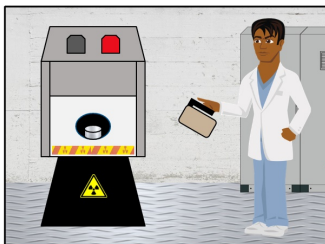


4.19 Knowledge Check

(Multiple Choice, 10 points, unlimited attempts permitted)

What must the operator use to verify the source of an Open Installation RGD is in its fully shielded condition?

- ☐ EPD alarm
- ☒ Calibrated and operable survey instrument
- ☐ Visual confirmation
- ☐ TLD
- ☐ No verification needed



Correct	Choice
	EPD alarm
X	Calibrated and operable survey instrument
	Visual confirmation
	TLD
	No verification needed

Feedback when correct:

That's right! You selected the correct response.


Correct (Slide Layer)

What must the operator use to verify the source of an Open Installation RGD is in its fully shielded condition?

- EPD alarm
- ☒ Calibration survey
- Visual check
- TLD
- No verification needed

Correct
That's right! You selected the correct response.

Continue



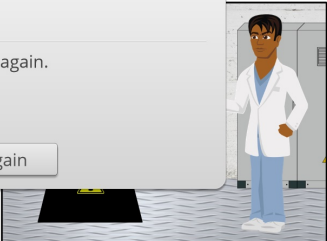
Try Again (Slide Layer)

What must the operator use to verify the source of an Open Installation RGD is in its fully shielded condition?

- EPD alarm
- ☒ Calibration survey
- Visual check
- TLD
- No verification needed

Incorrect
That is incorrect. Please try again.

Try Again



5. Module 1 - Radiation Protection Principles

5.1 Module 1 Objectives

Module 1 – Radiation Protection Principles

Upon completion of this module, the participants should understand basic radiation protection principles essential to the safe operation of radiation generating devices.

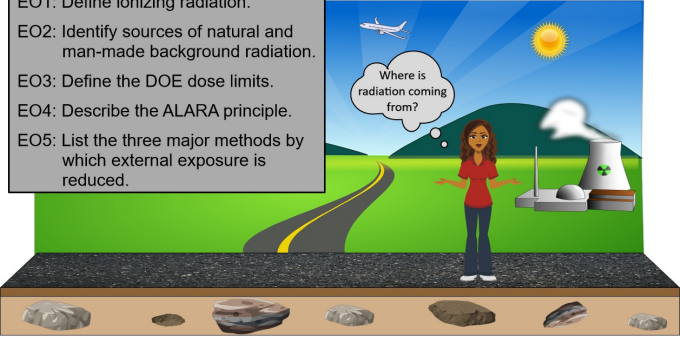
EO1: Define ionizing radiation.

EO2: Identify sources of natural and man-made background radiation.

EO3: Define the DOE dose limits.

EO4: Describe the ALARA principle.

EO5: List the three major methods by which external exposure is reduced.

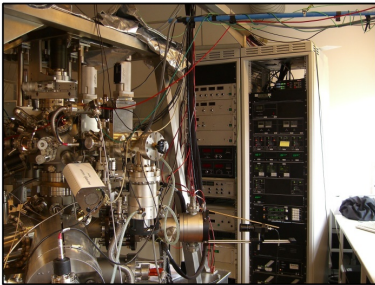


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5.2 Industry Event

Industry Event: X-ray Spectrometer Maintenance

On July 26, 1994, a 23-year-old engineer was repairing a 40-kV, 70-mA x-ray spectrometer. He removed several panels and inserted his hand for 5-6 seconds at a distance 6-8 cm from the x-ray tube before realizing that he had failed to de-energize the device. The engineer recalled having a sensation of tingling and itching in his fingers the day after the accident. A pinching sensation, swelling, and redness were present between days four and seven. By day seven, a large blister was developing, in addition to increased swelling.



X-Ray Photoelectron Spectrometer

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5.3 Industry Event

Industry Event: X-ray Spectrometer Maintenance

One month after the accident, the entire hand was discolored, painful, and extremely sensitive to the slightest touch. Blood circulation to the entire hand was low, especially to the index and middle fingers. Surgery was performed to sever the sympathetic nerve to allow the constricted blood vessels to dilate, and a skin graft was sutured in place. One month later, the hand had returned to a normal color and the skin graft was adherent. In July 1995, one year after the accident, his index finger started to itch and turn black with necrosis or gangrene. As a result, his finger was amputated.



5.4 Causes of Accidental Exposures

Causes of Accidental Exposures

Contributing Factors

- Rushing to complete a job
- Boredom
- Fatigue
- Illness
- Personal problems
- Lack of communication
- Complacency

How to Prevent

- Follow procedures
- Stay alert
- Review postings
- Do not deviate from plans
- RWP's
- Proper communication
- Questioning attitude



5.5 Atoms

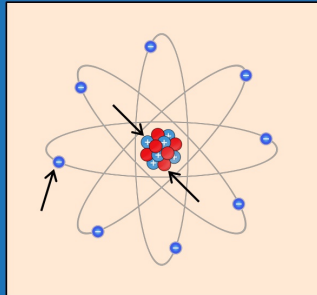
Atoms

The atom, the basic unit of matter, is made up of three primary particles: protons, neutrons, and electrons.

Protons and neutrons are found in the nucleus of the atom; electrons are found orbiting the nucleus.

- Protons – Positive Charge
- Neutrons – No Charge
- Electrons – Negative Charge

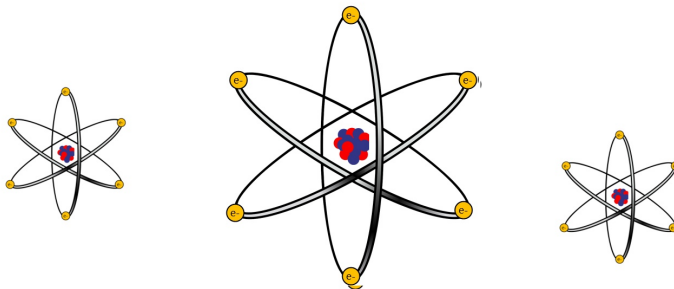
The configuration and number of electrons in the electron shells determines the chemical properties of atoms.



Notes:

5.6 Ionization

Ionization



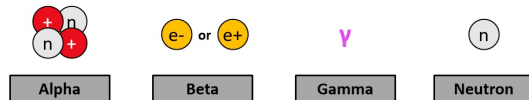
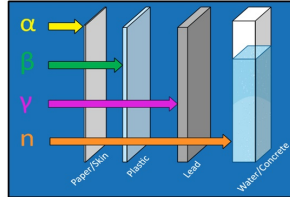
An atom usually has a number of electrons equal to the number of protons in its nucleus so that the atom is electrically neutral. A charged atom, called an ion, can have a positive or negative charge. Free electrons also are called ions. An ion is formed when ionizing radiation interacts with an orbiting electron and causes it to be ejected from its orbit, a process called *ionization*. This leaves a positively charged atom (or molecule) and a free electron.



5.7 Radiation

Radiation

Radiation - Alpha particles, beta particles, gamma rays, X-rays, neutrons, high-speed electrons, high-speed protons, and other particles capable of producing ions. Radiation with enough energy to cause ionization is referred to as *ionizing radiation* and radiation that lacks the energy to cause ionization is *non-ionizing radiation* (microwaves, visible light). Ionization affects chemical and biological processes and allows the detection of radiation.



X-rays and gammas are a form of electromagnetic radiation which differ from their point of origin. Gammas come from the atomic nucleus and X-rays originate from electrons outside the nucleus and from free electrons decelerating in the vicinity of atoms (bremsstrahlung).



5.8 Radiation Units

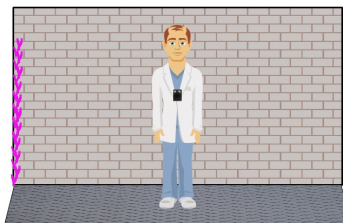
Radiation Units

Roentgen (R) - A measure of radiation *exposure*, is defined by ionization in air by X-rays of gamma radiation.

Rad - A measure of the energy absorbed per unit mass. It is defined for any absorbing material.

Rem - A unit of equivalent dose, which is the energy absorbed per unit mass times the applicable radiation weighting factor and other modifying factors.

For X-rays, it may be assumed that: $1 \text{ R} = 1 \text{ rad} = 1 \text{ rem} = 1,000 \text{ mrem}$



Notes:

5.9 Background Radiation

Background Radiation

Background radiation, to which everyone is exposed, comes from both natural and manmade sources. Natural background radiation can be categorized as either cosmic or terrestrial. Radon is the major contributor to terrestrial background. The most common sources of manmade background radiation are medical procedures and consumer products.

The average background dose to the general population from both natural and manmade sources is about 350 mrem/yr to the whole body.



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Naturally Occurring

Radon Daughters	~ 200 mrem/yr
Internal Emitters	~ 40 mrem/yr
Cosmic	~ 30 mrem/yr

Manmade

X-rays	~ 50 mrem/yr
Living near nuclear plant	~ < 1 mrem/yr

Notes:

5.10 Occupational Radiation Dose Limits

Occupational Radiation Dose Limits

	DOE Dose Limits	LANL Notification Limits
Whole Body (TEDE)	5 rem/year	1 rem/year
Extremity	50 rem/year	10 rem/year
Skin	50 rem/year	-
Internal Organ	50 rem/year	-
Lens of the Eye	15 rem/year	3 rem/year
Embryo/Fetus	0.5 rem/term of pregnancy	0.1 rem/term of pregnancy
Public/Minors	0.1 rem/year	-

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Notes:

5.11 ALARA



ALARA

Because the effects of chronic doses of low levels of ionizing radiation are not precisely known, we assume there is some risk for any dose. The ALARA principle is to keep radiation dose *As Low As Reasonably Achievable*.

The success of an ALARA Program is directly linked to a clear understanding and following of the policies and procedures for the protection of workers. Keeping radiation dose ALARA is the responsibility of all workers, management, and the radiation-protection organization.

Three basic ways to reduce external doses are to:

- Minimize time
- Maximize distance
- Utilize shielding

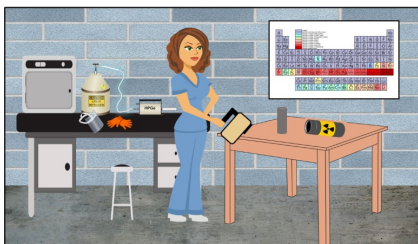
Notes:

5.12 Knowledge Check

(Multiple Choice, 10 points, unlimited attempts permitted)

Select the answer that contains the DOE Federal Dose Limits

- ☒ Whole Body Dose – 5 rem/yr, Extremities – 50 rem/yr, Minor/Public - 0.1 rem/yr
- ☐ Whole Body Dose – 15 rem/yr, Skin – 15 rem/yr, Minor/Public - 0.1 rem/yr
- ☐ Whole Body Dose – 5 rem/yr, Extremities – 50 rem/yr, Minor/Public – 5 rem/yr
- ☐ Whole Body Dose – 50 rem/yr, Skin – 50 rem/yr, Minor/Public – 0.5 rem/yr



Correct	Choice
X	Whole Body Dose – 5 rem/yr, Extremities – 50 rem/yr, Minor/Public - 0.1 rem/yr
	Whole Body Dose – 15 rem/yr, Skin – 15 rem/yr, Minor/Public - 0.1 rem/yr
	Whole Body Dose – 5 rem/yr, Extremities – 50 rem/yr, Minor/Public – 5 rem/yr
	Whole Body Dose – 50 rem/yr, Skin – 50 rem/yr, Minor/Public – 0.5 rem/yr

Feedback when correct:

That's right! You selected the correct response.


Correct (Slide Layer)

Select the answer that contains the DOE Federal Dose Limits

- ☒ Whole Body Dose – 5 rem/yr, Extremities – 50 rem/yr, Minor/Public – 0.1 rem/yr
- ☐ Whole Body Dose – 15 rem/yr, Skin – 15 rem/yr, Minor/Public – 0.1 rem/yr
- ☐ Whole B – 5 rem/yr
- ☐ Whole B – rem/yr

Correct
That's right! You selected the correct response.

Continue




Try Again (Slide Layer)

Select the answer that contains the DOE Federal Dose Limits

- ☒ Whole Body Dose – 5 rem/yr, Extremities – 50 rem/yr, Minor/Public – 0.1 rem/yr
- ☐ Whole Body Dose – 15 rem/yr, Skin – 15 rem/yr, Minor/Public – 0.1 rem/yr
- ☐ Whole B – 5 rem/yr
- ☐ Whole B – rem/yr

Incorrect
That is incorrect. Please try again.

Try Again



5.13 Knowledge Check

(Matching Drop-down, 10 points, unlimited attempts permitted)

Match the Description with the Term

Roentgen	A measure of radiation exposure, is defined by ionization in air by X-rays of gamma radiation.
Rad	A measure of the energy absorbed per unit mass. It is defined for any absorbing material.
Rem	A unit of equivalent dose, which is the energy absorbed per unit mass times the applicable radiation weighting factor and other modifying factors.
Proton	Positive charge
Neutron	No charge
Electron	Negative charge

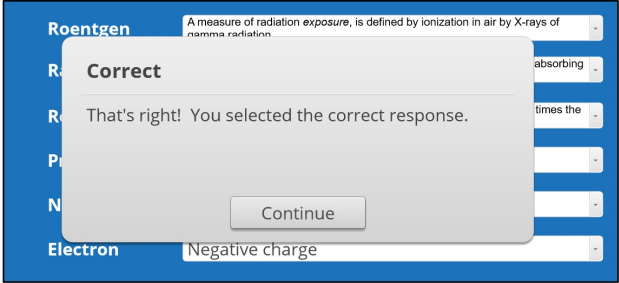
Correct	Choice
Roentgen	A measure of radiation exposure, is defined by ionization in air by X-rays of gamma radiation.
Rad	A measure of the energy absorbed per unit mass. It is defined for any absorbing material.
Rem	A unit of equivalent dose, which is the energy absorbed per unit mass times the applicable radiation weighting factor and other modifying factors.
Proton	Positive charge
Neutron	No charge
Electron	Negative charge

Feedback when correct:

That's right! You selected the correct response.

Correct (Slide Layer)

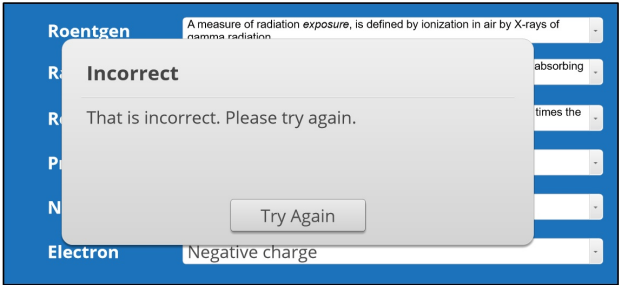
Match the Description with the Term



The screenshot shows a matching quiz interface with a blue background. On the left, a list of terms includes 'Roentgen', 'R', 'R', 'P', 'N', and 'Electron'. On the right, a list of descriptions includes 'A measure of radiation exposure, is defined by ionization in air by X-rays of gamma radiation.', 'absorbing', 'times the', and 'Negative charge'. A central grey dialog box displays the word 'Correct' in bold, followed by the text 'That's right! You selected the correct response.' and a 'Continue' button.

Try Again (Slide Layer)

Match the Description with the Term



The screenshot shows the same matching quiz interface as above. The central grey dialog box now displays the word 'Incorrect' in bold, followed by the text 'That is incorrect. Please try again.' and a 'Try Again' button.

6. Module 2 - Production of X-Rays

6.1 Module 2 Objectives

Module 2 – Production of X-Rays

Upon completion of this module, the participants should understand what X-rays are and how they are produced so that the participants will be able to work around them safely.

- EO1: Define the types of electromagnetic radiation.
- EO2: Describe the difference between X-rays and gamma rays.
- EO3: Identify how X-rays are produced.
- EO4: Define bremsstrahlung and characteristic X-rays.
- EO5: Describe how X-ray tube voltage and current affect photon energy and power.
- EO6: Explain how X-rays interact with matter.
- EO7: Identify how energy relates to radiation dose.
- EO8: Discuss the effects of voltage, current, and filtration on X-rays.

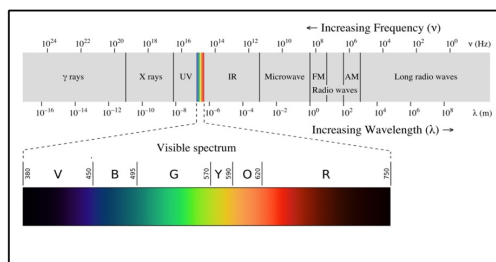


6.2 Types of Electromagnetic Radiation

Types of Electromagnetic Radiation

X-rays are a type of electromagnetic radiation. Other types of electromagnetic radiation are radio waves, microwaves, infrared, visible light, ultraviolet, and gamma rays. The types of radiation are distinguished by the amount of energy carried by the individual photons.

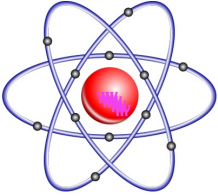
All electromagnetic radiation consists of photons, which are individual packets of energy. The energy carried by individual photons, which is measured in electron volts (eV), is related to the frequency of the radiation.



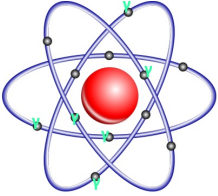
6.3 X-Rays and Gamma Rays

X-Rays and Gamma Rays

X-rays and gamma rays both ionize atoms. The energy required for ionization varies with material but is generally in the range of several eV. A 100 keV X-ray can potentially create thousands of ions.



Gamma rays originate from within the nucleus



X-rays originate from atomic electrons and free electrons decelerating (bremsstrahlung)

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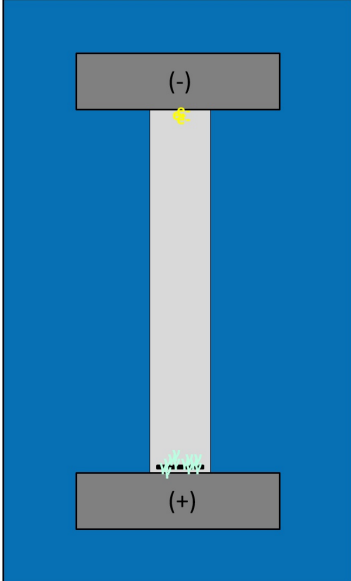
6.4 X-Ray Production

X-Ray Production

Radiation generating devices (RGDs) produce X-rays by accelerating through an electrical voltage potential and stopping them in a target. Many devices that use a high voltage and source of electrons produce X-rays as an unwanted byproduct of device operation. These are called *incidental* X-rays.

Most X-ray devices emit electrons from a cathode, accelerate them with a voltage, and allow them to hit an anode, which emits X-ray photons.

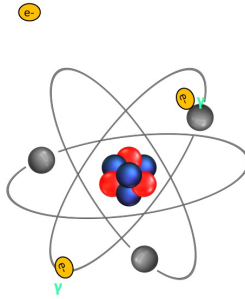
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6.5 Bremsstrahlung

Bremsstrahlung

When electrons hit the anode, they decelerate or brake emitting *bremsstrahlung* (meaning *breaking radiation* in German). The varying rates of braking cause X-ray photons to be produced by many individual energies over a wide energy spectrum. Bremsstrahlung is produced most effectively when small charged particles interact with large atoms such as when electrons hit a tungsten anode. However, bremsstrahlung can be produced with any charged particles and any target. For example, laboratories have produced bremsstrahlung from accelerating protons into hydrogen.

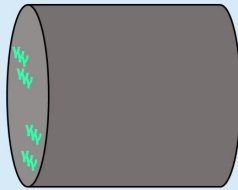


Notes:

6.6 Characteristic X-Rays

Characteristic X-Rays

High-speed electrons traveling in a vacuum that strike a target material may cause an electron to be freed from the target atom. The vacancy left by a freed electron is then filled by other electrons within the atom. The transition of electrons between energy states results in the emission of X-rays that are "characteristic" of the target atom identity.



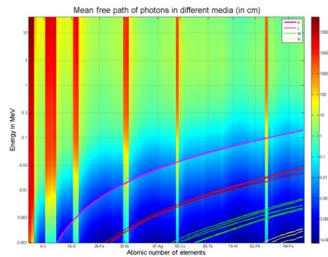
The energy of characteristic X-rays corresponds to the difference between the initial and final electron energy state. For example, when bombarded by high-velocity electrons in a vacuum, copper emits characteristic X-rays of 9.04 keV. In contrast, tungsten emits characteristic x-rays of 58.87 keV.



Notes:

6.7 Photon Energy and Power

Effect of Voltage and Current on Photon Energy and Power



It is important to distinguish between the energy of individual photons in an X-ray beam and the total energy of all the photons in a beam, as well as the difference between the average power and peak power in a pulsed X-ray device.

Typically, the individual photon energy is given in electron volts (eV), whereas the power of a beam is given in watts (W). An individual 100 keV photon has more energy than an individual 10 keV photon. However, an X-ray beam consists of a spectrum of photon energies and the rate at which energy is delivered by a beam is determined by the number of photons of each energy.

The photon energy distribution may be varied by changing the voltage. The number of photons emitted may be varied by changing the current.

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6.8 Voltage and Current

Voltage and Current

Voltage

- The photon energy produced by an RGD depends on the voltage, which is measured in volts (V). A voltage of 10 kV will produce up to 10-keV X-ray photons.
- Most of the X-ray photons produced by a given maximum electron acceleration potential will be approximately 1/3 of the maximum electron potential. For example, a 120-kV-peak (kvp) diagnostic RGD produces X-ray photons with an average of 40 keV.
- Whenever voltage is on, a device can produce X-rays even if the currents is too low to read.

Current

- The total number of photons produced by an RGD depends on the current, which is measured in amperes, or amps (A).
- The current is controlled by increasing or decreasing the number of electrons emitted from the cathode.
- The higher the electron current, the more X-ray photons emitted from the anode. Many RGDs have meters to measure the X-ray current produced.

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6.9 Total Power

Total Power

Power, which is measured in watts (W), equals voltage times current.

$$P = V \times I$$

For example, a 10 kVp device with a current of 1 mA uses 10 W of power.



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Example # 1

Power = 50 watts

Voltage = 25 kVp

Current = ?

$$P = V \times I \longrightarrow I = P / V$$

$$I = 50 / 25 = 2 \text{ mA}$$

Example # 2

Power = 80 watts

Current = 4 mA

Voltage = ?

$$P = V \times I \longrightarrow V = P / I$$

$$I = 80 / 4 = 20 \text{ kVp}$$

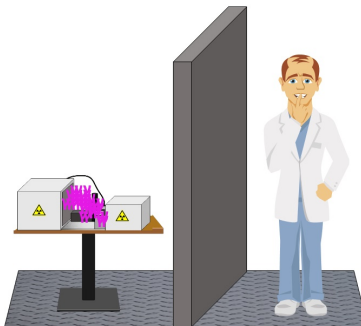
6.10 Scattering

Interaction with Matter - Scattering

When X-rays pass through any material, some will be transmitted, some will be absorbed, and some will scatter. The proportions depend on the photon energy and the type of material.

X-rays can scatter off a target to the surrounding area, off a wall and into an adjacent room, and over and around shielding. A common mistake is to install thick shielding walls around an X-ray source but ignore the need for a roof, based on the assumption that X-rays travel in a straight line.

The X-rays that scatter over and around shielding walls are known as *skyshine*. The emanation of X-rays through and around penetrations in shielding is called *radiation streaming*.



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6.11 Implications of Power and X-Ray Productions

Implications of Power and X-Ray Productions

When high-speed electrons strike the anode target, most of their energy is converted to heat, but a portion is radiated away as X-rays. The electrical power of a circuit is given by:

$$P = V \times I$$

The power developed in the anode of an X-ray tube can be calculated using this relationship. Consider a 150 kilovolt (kVp) machine, with a current of 50 milliamps.

$$P = [150,000 (V)][0.050 (I)] = 7,500 \text{ W}$$

This is about the same heat load as would be found in the heating element of an electric stove. Power is delivered over a very short period of time, typically less than 1 second. More powerful X-ray machines use higher voltages and currents and may develop power as high as 50,000 W or more. Cooling the anode is a problem that must be addressed in the design of X-ray machines. Tungsten is used because of its high melting point, and copper is used because of its excellent thermal conductivity.

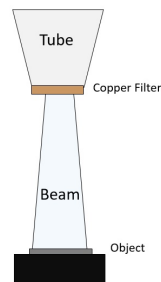


6.12 Filtration

Filtration

Low and high energy photons are sometimes referred to as soft and hard X-rays, respectively. Because hard X-rays are more penetrating, they are more desirable for radiography (producing a photograph of the interior of the body or apparatus). Soft X-rays are less useful for radiography because they are largely absorbed near the surface of the body being X-rayed. However, there are medical applications where the soft X-rays are useful.

- A filter, such as a few millimeters of aluminum, or copper may be used to harden the beam by absorbing most of the low-energy photons. The remaining photons are more penetrating and useful.
- In the X-ray analytical work, filters with energy selective absorption edges are not used to harden the beam, but to obtain a more monochromatic beam.
- By choosing the right element, it is possible to absorb a band of high-energy photons preferentially over an adjacent band of low energy photons.



6.13 Knowledge Check

(Numeric, 10 points, unlimited attempts permitted)

Calculate the Amps
(current) of the device with
the following known
variables:

Power = 80 Watts
Voltage = 10 Volts

Current = Amps



Acceptable numeric values

Equal to

8

Feedback when correct:

That's right! You selected the correct response.

Correct (Slide Layer)

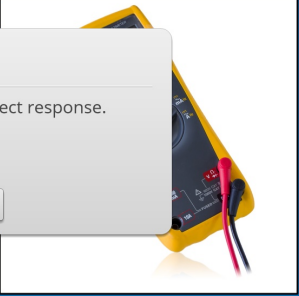
Calculate the Amps (current) of the device with the following variables:

Power = 120 Watts
Voltage = 120 Volts

Current = Amps

Correct
That's right! You selected the correct response.

Continue



Try Again (Slide Layer)

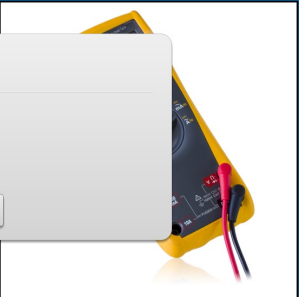
Calculate the Amps (current) of the device with the following variables:

Power = 120 Watts
Voltage = 120 Volts

Current = Amps

Incorrect
That is incorrect. Please try again.

Try Again




7. Module 5 - Protective Measures


7.1 Module 5 Objectives

Module 5 – Protective Measures

TO1: Upon completion of this module, the participants should understand protective measures that restrict or control access to X-ray areas and devices or warn of X-ray hazards, and should be able to use work documents that provide specific procedures to ensure safe operation of X-ray devices.



- EO1: Identify and state specific administrative and engineered controls.
- EO2: Identify and state specific radiological postings.
- EO3: Define "interlocks".
- EO4: Explain specific shielding practices.
- EO5: Identify typical RPD warning devices.
- EO6: Outline site-specific work documents.




7.2 Maintaining ALARA

Maintaining ALARA

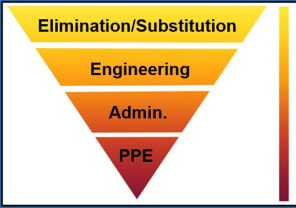
To control radiation exposure, as well as maintain exposure ALARA, working with and around RGDs is restricted by a combination of administrative and engineering controls.

- Elimination/Substitution – Remove or replace the hazard
- Engineering controls – Isolate people from the hazard
- Administration controls – Change the way people work
- PPE – Protect the worker with personal protective equipment



Hierarchy of Hazard Controls

Most effective





Least effective

7.3 Administrative and Engineering Controls

Administrative and Engineering Controls



Administrative Controls


- Postings
- Warning signals and labels
- Work control documents such as IWDs and RWP



Engineering Controls

- Interlocks
- Shielding






7.4 Controls for HRA

Controls for High Radiation Areas

For high-radiation areas where radiation levels exist such that an individual could exceed an equivalent dose to the whole-body of 1 rem in any 1 hour at 30-cm from the source or surface that the radiation penetrates, one or more of the following features shall be used to control exposure:

- A control device that prevents entry
- A device that prevents use of the radiation source when personnel are present
- A device that energizes a visible and audible alarm
- Locked entry ways
- Continuous direct or electronic surveillance to prevent unauthorized entry
- A device that generates audible and visual alarms in sufficient time to permit evacuation

In addition to the above measures, for very high radiation areas (> 500 rad/hr), additional measures shall be implemented to ensure individuals are not able to gain access.



7.5 Radiological Posting

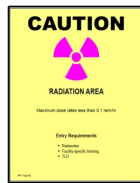
Radiological Posting

The two primary reasons for radiological posting are:

1. To inform workers of the radiological conditions.
2. To inform workers of the entry requirements for an area.

General Posting Requirements

1. Signs contain the standard radiation symbol colored magenta or black on a yellow background.
2. Signs shall be clearly and conspicuously posted to alert personnel to the presence of radiation. Signs may also include radiological protection instructions.

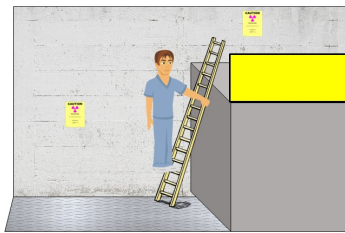
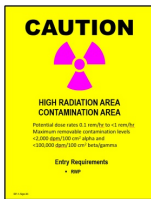


7.6 General Posting Requirements

General Posting Requirements

General Posting Requirements

3. If more than one radiological condition exists in the same area, each condition should be identified.
4. Rope, tape, chain, or similar barrier material used to designate radiological areas should be yellow and magenta.
5. Physical barriers should be placed so that they are clearly visible from all accessible directions and at various elevations.



7.7 General Posting Requirements

General Posting Requirements

- Posting of doors should be such that they remain visible when doors are open or closed.
- Radiological postings that indicate an intermittent radiological condition should include a statement specifying when the condition exists, such as:

"CAUTION, RADIATION AREA WHEN RED LIGHT IS ON"

- For a Radiation Area, wording on the posting shall include the words:

"CAUTION, RADIATION AREA "

- For a High Radiation Area, wording on the posting shall include the words:

"CAUTION, HIGH RADIATION AREA " or "DANGER, HIGH RADIATION AREA"

- For a Very High Radiation Area, wording on the posting shall include the words:

"GRAVE DANGER, VERY HIGH RADIATION AREA"



7.8 Labels

Labels

Three types of labels associated with RGDs at LANL include:

Control Panel Labels

The control panel of an intentional RGD must be labeled with the words
**CAUTION – THIS EQUIPMENT
PRODUCES X-RAYS
WHEN ENERGIZED**



Compliance Labels

An RGD that has been surveyed by the RGD Control Office and meets safe operating requirements displays a LANL x-ray compliance label

RGD Compliance Label	
This device has a current compliance survey and inspection by the LANL RGD office.	
PN / SN	RGD #
Resurvey Date: Month	Year
RGD Surveyor	Date

Warning Labels

A device that fails to meet all appropriate safety requirements displays a warning label indicating that the device must not be used

WARNING	
DO NOT USE THIS MACHINE	
It does not meet applicable radiation safety standards and operational requirements.	
RGD #	PN/SN
RGD Office	Date

7.9 Interlocks

Interlocks

Fail-safe interlocks should be provided on doors and access panels of RGDs so that X-ray production is not possible when they are open. A fail-safe interlock is designed so that any failure that can reasonably be anticipated will result in a condition in which personnel are safe from excessive radiation exposure.

Interlock checks must be developed specifically for each applicable RGD with focus on proper configuration and functions of features important to the safe operation of that RGD (including shielding, emergency stop switches, warning lights postings, and other controls as applicable). Interlocks must be tested by the operating group at least every six months.

6-Month Interlock Checklist – Before x-rays are operated each day, it must be ensured that this checklist has been completed within the previous 6-months, was logged in the x-ray booklet that is kept near the x-ray control console, and passed. In addition to ensuring that all aspects of the safety system, signage, x-ray surveys, this IWD, and operator qualifications and authorizations are in order, this checklist requires that every break point of the interlock system is verified in good order. This is completed by breaking the x-ray system interlock at every interlocked point by repeatedly enabling the charging system without charging and then ensuring that it is properly disabled when the respective interlock point is broken. This check is logged in the x-ray booklet that is kept near the x-ray control console, and if all aspects of the checklist pass, this check passes. If all aspects of the checklist do not pass, this test fails and any respective x-ray systems cannot be operated until the interlock system works as designed and can pass this check again.

Interlock checklist example of M-3 Firing Site Low Energy X-ray Operations



7.10 Shielding



Shielding

- For analytical X-ray machines, such as X-ray fluorescence and diffraction systems, the manufacturer provides shielding in accordance with ANSI N43.2
- Some industrial X-rays systems, such as the cabinet X-ray systems used for airport security, are completely enclosed in an interlocked and shielded cabinet
- Larger systems, such as X-ray units, are enclosed in a shielded room to which access is restricted
- Shielding for X-ray rooms is designed to handle the most severe operating conditions of the X-ray machine
- During annual surveys, RCTs verify that shielding integrity has not deteriorated or been compromised

7.11 Shielding

Shielding

RGD Control Office personnel develop recommendations for shielding based on the following:

- Type of source
- Voltage or energy
- Amperage or current
- Contemplated use
- Expected workload
- Structural details of the building
- Type of occupancy for all affected areas



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7.12 Warning Devices

Warning Devices

Warning devices are used to alert workers to the status of the X-ray tube. Visible indicators that are activated automatically when power is available for X-ray productions includes:

- A meter that indicates "CURRENT" on the RGD control panel
- A fail-safe light with the words "X-RAYS ON" near or on the RGD control panel
- A warning light or rotating beacon near the RGD or the X-ray room door
- A fail-safe "SHUTTER OPEN" indicator for beam shutters



For X-ray systems with an open beam in a shielded room, audible and visible evacuation warning signals must be activated at least 20 seconds before ray production can be started. An audible warning that will signal when an interlock is broken is also required.

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7.13 SCRAM Switch

SCRAM Switch

A SCRAM switch is a safety device, installed within a radiation generating facility (RGF) or enclosure in which workers enter in the course of x-ray operations, that when manually activated, prevents or interrupts the productions of X-rays from the RGD. SCRAM switches are wired to the RGD control panel so that X-ray production cannot be resumed unless the SCRAM switch is reset.

- Any person who is inside the exposure room when warning signals sound should immediately leave the room or activate the SCRAM switch in the room.



The acronym "SCRAM" historically meant either to "safety control rod ax man" or "sudden control rod activation by manual mean"

7.14 Integrated Work Document

Integrated Work Document (IWD)

All RGDs must be operated using approved work control documents in accordance with integrated work management (IWM) requirements.

- A high-hazard RGD requires an IWD and RWP
- A moderate-hazard RGD requires an IWD and either an RWP or Facility Radiation Protection Requirements (FRPR) document
- IWDs or RWPS are not required for low-hazard radiological work
- In all cases, manufacturer's instructions, including shielding, controls, operating parameters, and required maintenance must be followed
- In addition to defining the work, an IWD must identify the hazards and describe the controls

Note: Modifications to RGD design, controls, or accessories from the manufacturer's operating procedures require a review by RP-PROG for hazard analysis and control definition.



7.15 Radiological Work Permit


Radiological Work Permit (RWP)

RWPs are used to establish radiological controls for entry into radiological areas. They serve to:

- Inform workers of area radiological conditions
- Inform workers of entry requirements into the areas
- Provide a means to relate radiation doses to specific work activities

RWPs are used in conjunction with RGDs when:

- The dose rate generated is > 1 R/hr at 30 cm
- A portable RGD for a one-time operation is not described in the X-ray's existing IWD
- A non-routine event requires an operator to enter the radiation exposure room when the X-ray beam is on or the RGD source is exposed and radiation is being produced so that either a HRA or VHRA exists







7.16 Knowledge Check

(Multiple Choice, 10 points, unlimited attempts permitted)

Which label is not associated with RGDs?

- Compliance Label
- Control Panel Label
- Warning Label
- Caution Label



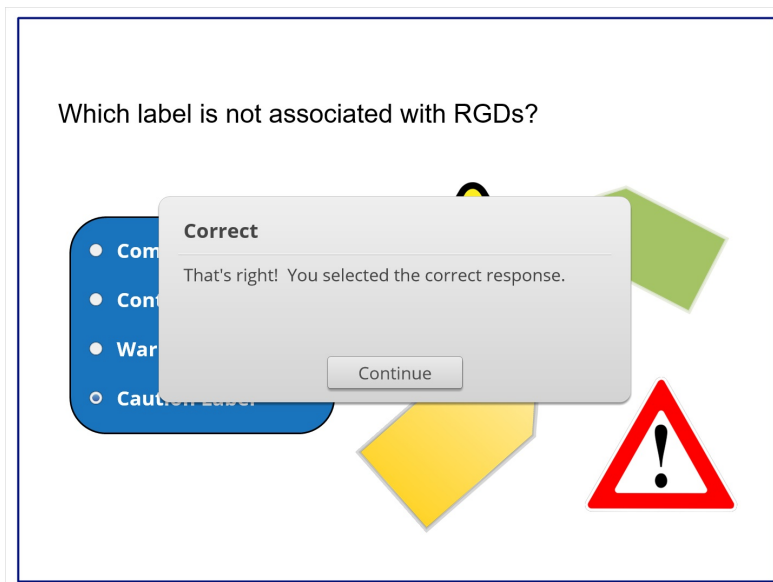
Correct	Choice
	Compliance Label

	Control Panel Label
	Warning Label
X	Caution Label

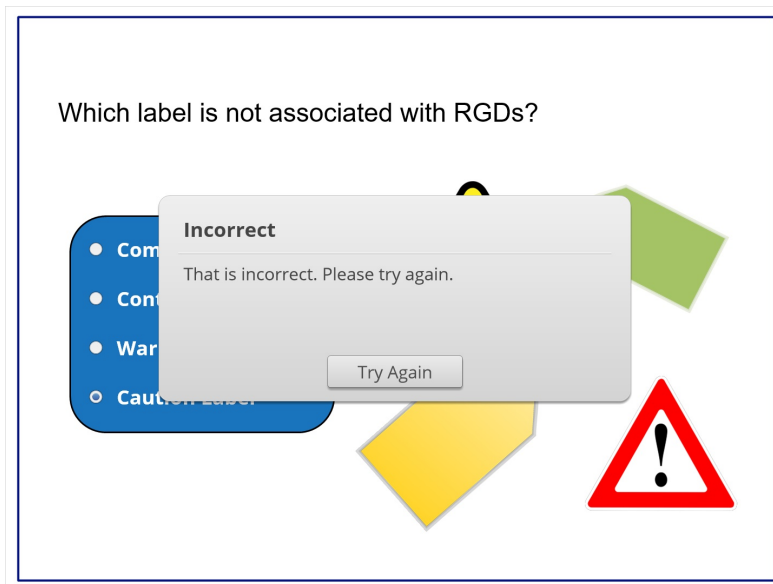
Feedback when correct:

That's right! You selected the correct response.

Correct (Slide Layer)

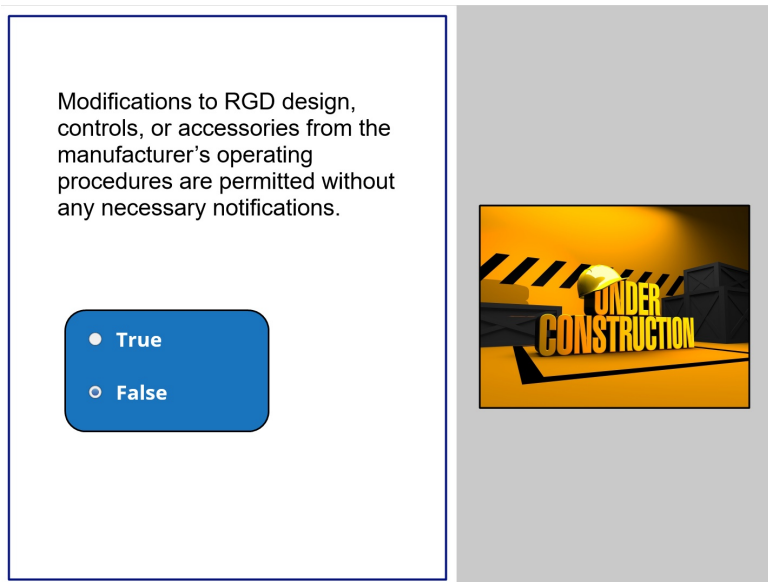


Try Again (Slide Layer)



7.17 Modifications to RGD design, controls, or accessories from the manufacturer's operating procedures are permitted without any necessary notifications.

(True/False, 10 points, unlimited attempts permitted)

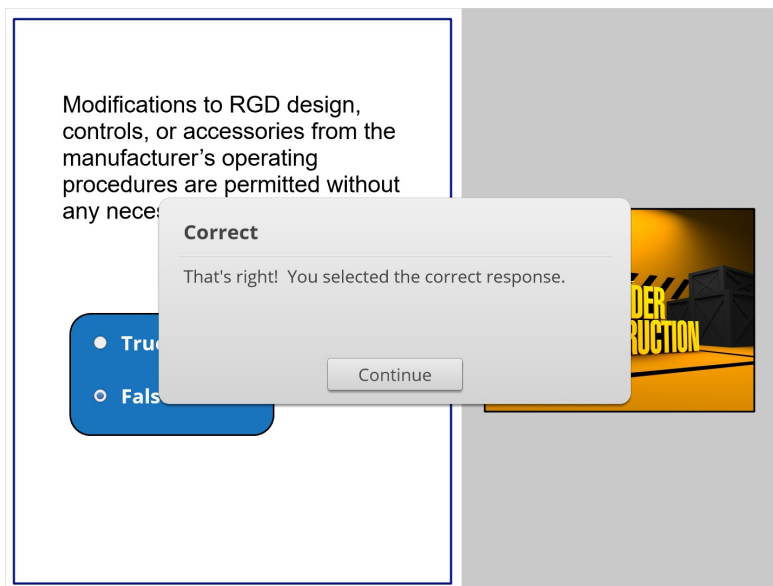


Correct	Choice
	True
X	False

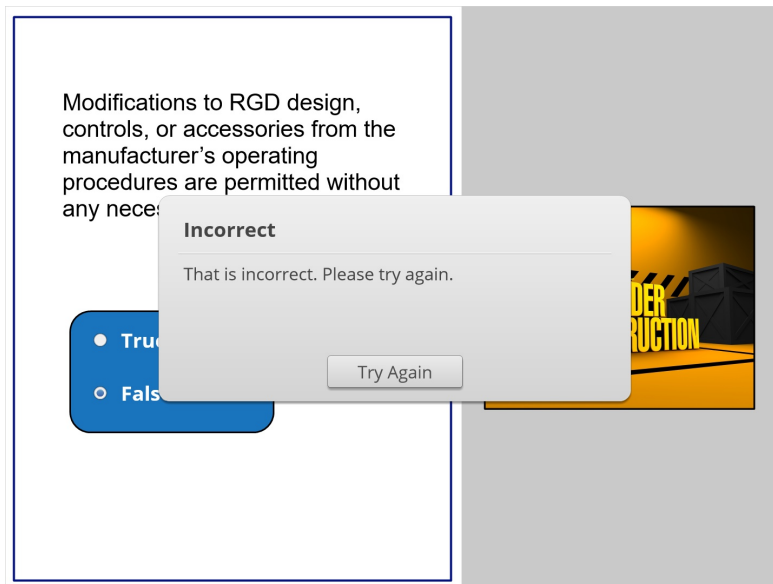
Feedback when correct:

That's right! You selected the correct response.

Correct (Slide Layer)



Try Again (Slide Layer)



8. Module 7 - Responsibilities For X-Ray Safety

8.1 Module 7 Objectives

Module 7 – Responsibilities For X-Ray Safety

TO1: Upon completion of this module, the participants will understand who is responsible for implementing RGD safety policies and procedures and what their specific responsibilities are.


EO1: State the responsibilities of the RGD Control Office.
EO2: State the responsibilities of operating groups regarding RGD safety.
EO3: State the responsibilities of RGD custodians.
EO4: State the responsibilities of RGD operators.

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8.2 Responsibilities

Responsibilities

The responsibility for maintaining exposures from RGDs ALARA is shared among the RGD Control Office, the operating groups, RGD device custodians, RGD operators, and the RP division. Additional responsibilities of personnel and groups can be found within P121, Chapter 18.



Who	Must
Facility Operations Directors (FODs)	• Ensure that all radiation generating device (RGD) operations are appropriately captured in safety basis processes and documentation.
Responsible Line Managers (RLMs)	• Ensure that the requirements for RGD custodians and operators specified in this chapter are implemented. • Assign RGD custodian(s) and RGD operator(s), ensure they are appropriately trained, and ensure custodians are captured in the RGD database. • Ensure RGD startup requirements are implemented for all new RGDs. • Ensure that RGD operations are conducted in accordance with Integrated Work Management (IWM) requirements. • For LANL-owned RGDs used off-site, ensure that installation and operation meet applicable requirements per Article 113.3.
RGD Custodians	• Provide direct control, including access control, over RGD operations in accordance with approved work control documents. • Ensure requirements in this chapter for compliance surveys, approach surveys, training, and safety feature inspections are implemented. • Ensure requirements in this chapter for RGD database information, accountability, startup, use, and disposition are implemented.
RGD Operators	• Operate only those RGDs authorized in accordance with approved work control documents. • Conduct RGD operations in accordance with the requirements in this chapter for RGD safety and interlock inspection and use. • Immediately report any unsafe operation or malfunction that impacts the safety of the RGD to the RGD custodian, RLM, and RP-PROG RGD Office.



8.3 RGD Control Office

Radiation Generating Device Control Office

The RGD Control Office is responsible for:

- Manage the institutional RGD control program
- Perform radiological design, design review, and evaluations of RGDs, installations, and facilities
- Serve as SMEs for Integrated Work Documents (IWDs), engineered controls, interlocks, and other access controls associated with RGDs
- Conduct compliance surveys/inspections of RGD installations as specified in P121, Chapter 18
- Remove RGDs from service by placing an "Out-of-Service" tag on RGDs and informing custodians the required steps for remediation
- Support requirements for RGD database information, accountability, startup, labeling, use, and disposition
- Authorize subcontractors to use RGDs at LANL

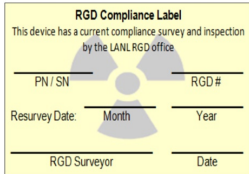


Figure 7. RGD Compliance Label






Figure 9. RGD Red Tag



8.4 Operating Groups

Installation Type	Required Training	
	Custodian	Operator/Other
Unattended (P121 Article 1832)	None	None
Certified Cabinet (P121 Article 1833)	RW & RGD Safety	GEOT
Emergency Shutdown (P121 Article 1834)	RW & RGD Safety	GEOT
Shutdown (P121 Article 1835)	RW & RGD Safety	RW & RGD Safety
Open (P121 Article 1836)	RW & RGD Safety	RW & RGD Safety
Accountable source use with a device (also see RGD)	RW, RGD Safety & RSS Safety	RW, RGD Safety & RSS Safety



Click Here To Access Your Training

Operating Groups

Operating groups are responsible for:


- Ensure that the requirements for RGD custodians and operators specified in P121, Chapter 18 are implemented
- Assign RGD custodian(s) and RGD operator(s), verify they have completed any required training, and ensure custodians are captured in the RGD database
- Ensure RGD startup requirements are implemented for all new RGDs
- Ensure RGD operations are conducted in accordance with Integrated Work Management (IWM) requirements
- For LANL-owned RGDs used off-site, ensure that installation and operation meet the state and/or local requirements


8.5 RGD Custodians

RGD Custodians

RGD custodians are responsible for:

- Provide direct control, including access control, over RGD operations in accordance with approved work control documents
- Ensure requirements for P121, Chapter 18 for compliance surveys, approach surveys, training, and safety feature inspections are implemented
- Ensure requirements for P121, Chapter 18 for RGD database information, accountability, startup, use, and disposition are implemented
- Verify that a copy of the most recent radiation protection survey performed by RP-PROG and a list of custodians and operators are available at or near the operator control panel for each RGD
- Ensure that the compliance label is present on the operator control panel before operating the RGD






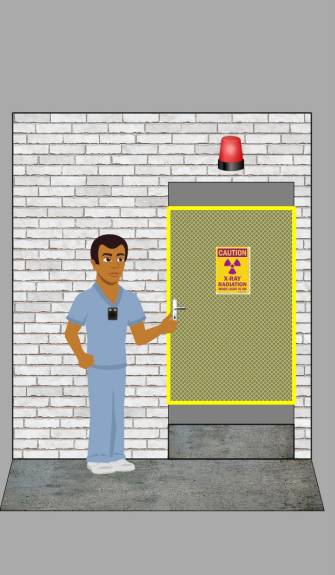
8.6 RGD Operators

RGD Operators

RGD operator's responsibilities:

- Only operate RGDs authorized in accordance with approved work control documents
- Conduct RGD operations in accordance with the requirements in P121, Chapter 18 for RGD safety and interlock inspection and use
- Ensure that required dosimeters are worn by all individuals in the vicinity of RGD operations
- Establish and maintain control of the RGD exposure area and affected adjacent areas
- Immediately report any unsafe operations or malfunctions that impacts the safety of the RGD to the RGD custodian, RLP, and the RP-PROG RGD Office






8.7 Knowledge Check

(Multiple Choice, 10 points, unlimited attempts permitted)

What is a responsibility of an RGD operator?

- Only operate RGDs authorized in accordance with work control documents
- Conduct RGD operations in accordance with P121 requirements
- Ensure that required dosimeters are worn by all individuals in the RGD vicinity
- Establish and maintain control of the RGD exposure area and adjacent areas
- Immediately report unsafe operations or malfunctions of the RGD
- All of the above



Correct	Choice
	Only operate RGDs authorized in accordance with work control documents

	Conduct RGD operations in accordance with P121 requirements
	Ensure that required dosimeters are worn by all individuals in the RGD vicinity
	Establish and maintain control of the RGD exposure area and adjacent areas
	Immediately report unsafe operations or malfunctions of the RGD
X	All of the above

Feedback when correct:

That's right! You selected the correct response.

Correct (Slide Layer)


What is a responsibility of an RGD operator?

- Only operate RGDs authorized in accordance with work control documents
- Conduct RGD operations in accordance with P121 requirements
- Ensure that required dosimeters are worn by all individuals in the RGD vicinity
- Establish and maintain control of the RGD exposure area and adjacent areas
- Immediately report unsafe operations or malfunctions of the RGD
- All of the above

Correct

That's right! You selected the correct response.

Continue



Try Again (Slide Layer)

What is a responsibility of an RGD operator?

- Only operate RGDs authorized in accordance with work control documents
- Conduct RGD operations in accordance with R123 requirements
- Ensure that RGDs are properly maintained in the RGD vicinity
- Establish and maintain safe work areas
- Immediate reporting of any RGD malfunctions
- All of the above

Incorrect

That is incorrect. Please try again.

Try Again

